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SOME EARLY THEORIES REGARDING ELECTRICAL FORCES—THE ELECTRIC EMANATION THEORY

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SINCE our present electrical theories have arisen from earlier theories by modifications made necessary by later discoveries, any clear understanding of our present view-point makes it necessary to know the steps by which it has been attained. It is the purpose of this paper to discuss the opinions regarding the nature of electrical action which were held by some of the early investigators who were most influential in determining scientific opinion.

The origin of our knowledge of the attraction of rubbed amber for other bodies is lost in the obscurity of the past, but no attempt to explain this striking phenomenon in scientific terms seems to have been made until Dr. William Gilbert published his famous treatise, *De Magnete*, in 1600. Gilbert showed that the power of attracting other bodies could be developed in many substances besides amber; but he learned of no other property of electrified bodies except this attraction for other bodies. This is, accordingly, the only fact which Gilbert's electrical theory was called upon to explain.

Gilbert proposed a true physical theory to account for this fact. He definitely rejected any possibility of action at a distance, and assumed that electric and magnetic attractions must be brought about by means of some intervening medium. Thus he says:[1]

> For as no action can be performed by matter save by contact, these electric bodies do not seem to touch, but of necessity something is given out from the one to the other to come into close contact therewith, and to be a cause of incitation to it.

He regards the medium which is responsible for electric attraction as different from and as more attenuated than air or water vapor. Thus he says:[2]

> All bodies are united and, as it were, cemented together by moisture, and hence a wet body on touching another body attracts it if the other body be small; but the peculiar effluvia of electrics, being the subtilest matter of solute moisture, attract corpuscles. Air, too, (the earth's universal effluvium) unites parts that are separated, and the earth, by means of the air, brings back bodies to itself: else bodies would not so eagerly seek the earth from

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[1] *De Magnete*, Mottelay's translation, p. 92.

[2] *De Magnete*, pp. 87-97.

> heights. The electric effluvia differ much from air, and as air is the earth's effluvium, so electric bodies have their own distinctive effluvia; and each effluvium has its own individual power of leading to union, in its own movement to its origin, to its fount, and to the body which emits the effluvium. But bodies that give out a thick or a vaporous or an aerial effluvium when rubbed have no effect; for either such effluvia are diverse from humour (unifier of all things), or, being very like the common air, they become blended with the air and one with it: wherefore they have no effect in the air, and do not produce any movements different from those of that universal and common element.
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> And in the air the effluvium of electrics is very rare, and so it may more thoroughly permeate the atmosphere and yet not give it impulsion by its own motion. For were this effluvium as dense as air, or the winds, or fumes of burning saltpeter, or as the thick foul effluvia emitted with much force from other bodies, or as the air from vapourized water rushing forth as from a pipe (as in the instrument described by Hero of Alexandria in his book *Spiritualia*): in such case it would repel everything, and not attract. But these thinner effluvia lay hold of the bodies with which they unite, enfold them, as it were, in their arms, and bring them into union with the electrics; and the bodies are led to the electric source, the effluvia having greater force the nearer they are to that.

The theory that an invisible emanation of some kind was given out by electrified bodies was generally held for 150 years after Gilbert's time; but there was no general agreement as to how such an emanation could bring together bodies at a distance from each other. Gilbert, as indicated above, believed that bodies are held to the earth by some kind of pressure of the air, or, perhaps, by means of the moisture of the air. He accordingly attributed similar properties to the hypothetical atmospheres caused by electric and magnetic emanations.

The Rev. John Lyon, in his *Experiments and Observations on Electricity*, published in 1780, describes the different electrical theories with which he was acquainted. He says:

> The first theory I shall mention is that of the learned F. Cabeus (1585-1650), who supposed that excited amber emitted effluvia from it, which expelled the neighboring air at small distances, and they made as it were a little whirlwind by the resistance they met with from the remoter air, which was not effected by the electric streams. When this subtle effluvia could not advance any further, by reason of the resistance of the distant air, he imagined they suddenly returned to the excited amber, and carried such light bodies with them as they met with in their way.
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> Sir Kenelm Digby, Mr. Boyle, Hartman, and others, supposed that excited amber emitted certain unctuous effluvia, which being cooled and condensed by the circumambient air, were deprived in part of their agitations, and shrinking back to the body from whence they issued, took with them such light substances as happened to adhere to their extreme particles at the time of their retractions.
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> The learned Gassendus approved of the foregoing theory, but he thought proper to add, that electric rays being emitted in several directions, intersected each other, and getting into the pores of light bodies, by means of their intersections, had the faster hold, and they drew with them chaff and straws, and other substances, in their returning to the amber from whence they were emitted.[3]

It will be seen that attraction is the only phenomenon thus far explained by means of effluvia. Nicolas Cabeus, who wrote his *Philoso-*

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[3] These electric rays of Gassendus almost seem to have their modern counterpart in the "tubes of force" of some of the English physicists of the present generation.

phia Magnetica in 1629, and who is referred to by Lyon as F. Cabeus, was evidently the first to observe repulsion between electrified bodies. In Chapter XXX., page 139, of the *Philosophia* he says:[4]

> I am convinced that this emanation attracts by setting the air in motion and that the air made to move in a whirl catches up the small bodies in the manner I have explained.
>
> If a face of the amber be carefully prepared (i. e. by rubbing) and is then applied to iron filings, wood shavings or similar bodies, they will be drawn strongly to the amber, but when they reach it, they will fly back and instead of falling straight downward, they will be repelled to a distance of three or four inches. It is evident then that this motion of the small bodies is on account of the movement of the air which arises (in turn) from the emanation, by which also the bodies are projected to a distance. For if it were the propulsion of the small bodies as Gilbert says, with the emanation becoming strong near the amber, they would fly back to the amber and would not be projected, just as in the case of the magnet, iron never flies back and is not repelled on coming to the magnet. But since in this case the body subject to propulsion does fly back, it is evident that the movement is caused by some external influence, undoubtedly the air.

It is plain from the above quotation that Cabeus did not recognize repulsion as a true property of electrification. Nor was it so recognized by others until the publication by Otto von Guericke of his paper, *De Virtutibus Mundanis,* in 1672.

Von Guericke recognized what he regarded as a true repulsion of his electrified sulphur globe for light bodies in its vicinity, but his explanation of the phenomenon was rather metaphysical than physical. He definitely rejected the hypothesis of an attraction by means of an atmosphere of emanation because he found that his sulphur globe could transmit its attractive power to a distance of a meter or more by means of a linen thread. The importance of this latter observation seems to have been overlooked until it was re-discovered nearly 60 years later by Stephen Gray.

Von Guericke, as the title of his paper implies, undertook to describe the various corporeal and incorporeal powers which he regarded as inherent in the nature of physical bodies. Some of these he classed as moving powers, of which repulsion was an example, and others were called conserving powers, such as gravitation. Electric attraction was classed as a conserving power and electric repulsion as a moving power. Since these powers were supposed to be inherent in the bodies themselves, they were not dependent upon a surrounding medium, and hence were of the nature of action at a distance.

In a further discusison of the various theories of electric effluvia, Lyon says:

> These theories had each their advocates in that age of Philosophy, in which they supposed that the effluvia emitted from an electric, returned to it again. After Sir Isaac Newton demonstrated the extreme subtility of the rays of light, and proved that several bodies might emit light copiously without any diminution of their weight: the doctrine of the return of effluvia was found unnecessary, and consequently was soon universally given up.

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[4] Translation by Professor Jefferson Elmore.

This explanation of the abandonment of a belief in electric effluvia seems to have been influenced by Lyon's own hypothesis, which was that the light corpuscles of Newton's theory constituted the real electric fluid. Notwithstanding this explanation, the belief in an electric effluvium of some kind was retained for a long time after Newton's work on Light. In fact, Newton, himself, believed in some kind of an electric emanation. In 1675 he transmitted to the Royal Society his description of an experiment showing that a sheet of glass which has been electrified by rubbing on one side may attract light bodies to its other side, and he interpreted this as showing that the electric emanation was capable of passing through glass. He also, refers to the great tenuity of the electric emanation in two places in his *Opticks*. On page 315, he says:

> So also a globe of glass about 8 or 10 inches in diameter being put into a Frame where it may be swiftly turned around its Axis, will in turning shine where it rubs against the palm of one's Hand apply'd to it: And if at the same time a piece of white Paper or white Cloth, or the end of one's Finger be held at a distance of about a quarter of an Inch or half an Inch from that part of the Glass where it is most in motion, the electric Vapour which is excited by the friction of the Glass against the Hand, will by dashing against the white Paper, Cloth or Finger, be put into such an agitation as to emit Light, and make the white Paper, Cloth or Finger, appear lucid like a Glow-worm: and in rushing out of the Glass will sometimes push against the Finger so as to be felt.

Again, on page 327, in discussing the possibility of an all pervading ether, he says with regard to the objection of the necessary rarity of such a medium:

> Let him also tell me, how an electrick Body can by Friction emit an exhalation so rare and subtile, and yet so potent, as by the Emission to cause no sensible diminution of the weight of the electrick Body, and to be expanded through a Sphere, whose Diameter is above Two Feet, and yet to be able to carry up Leaf Copper, or Leaf Gold, at a distance of above a Foot from the electrick Body.

It seems likely that the proof that electrified bodies may retain their power of attracting other bodies for an indefinite time after being charged was one of the principal reasons for abandoning the hypothesis of a returning effluvium carrying light bodies with it. Probably the most important of these observations was due to Stephen Gray. In 1729 Stephen Gray found that many bodies, such as rosin, shellac, pitch, beeswax and sulphur, when once electrified might retain their attractive power for months, or even years, which seemed to show very clearly that electric attraction was not due to the return of the electric effluvium to its source, as Gilbert had imagined.

Gray also made another important discovery which was difficult to explain in terms of an electric emanation. He observed that a body may be given the power of electric attraction by merely bringing an electrified body near it. He performed this experiment with a ball suspended from the end of a cord more than 800 feet long, and showed that light bodies were attracted to the ball when an electrified glass tube was brought near to the farther end of the cord. One of his favorite experiments was to suspend a boy in a horizontal position by means of loops of hair or silk and to place a table on which were some scraps of metal foil just below his head. Then when he brought his electrified tube near the boy's feet the scraps of foil rose at once to his face.

Nevertheless, fifty years after the publication of the discoveries of Stephen Gray we find physicists still explaining electric attractions and repulsions by means of an electric atmosphere surrounding the charged body. The Earl of Stanhope, who did distinguished work in the field of atmospheric electricity, published an important work in 1779[5] in which he gave the most truly scientific explanation of electrical attraction and repulsion by means of an electric atmosphere to be found in the writings of any philosopher. Stanhope does not regard the electric atmosphere as consisting of a separate emanation from the charged body, but as made up of the particles of air which have become charged with the electric fluid of Franklin, probably by contact with the charged body.

Like Stephen Gray, Stanhope tried the effect of placing a charged cork ball electroscope under the receiver of an air pump and noting the distance of separation of the cork balls as the air was exhausted. He found that the cork balls which had stood 2½ inches apart in the air fell to a separation of less than a quarter of an inch when the atmospheric pressure was about ¼ inch of mercury. He concluded from this experiment that the force of repulsion between the cork balls was proportional to the density of the air between them. Then he says:

> From these Experiments, it appears, that, when Bodies are charged with Electricity, it is the *Particles of (circumambient) Air being electrified,* that constitutes the electrical Atmosphere which exists around these Bodies.
>
> Now, since an *Electrical Atmosphere* (whether *negative* or *positive*) consists of electrified Air; it evidently follows, that the *Density* of the Electricity of that Air, must be in some *inverse Ratio of the Distance* from the charged Body, which causes that electrical Atmosphere.
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> That electrical Atmospheres do decrease *in density,* the more the Distance from the electrified Body is increased, is demonstrable by means of a proper Electrometer, in every instance.
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> From these simple considerations, it is easy to reduce all the different *Phenomina* of electrical *attraction* and *repulsion,* to *one* plain and convenient Principle, derived from the very nature of a *disturbed electrical Equilibrium;* namely, to the elastic tendency of the electrical Fluid, to impel every Body, charged either in *plus* or *in minus,* towards *that Part* of its electrical Atmosphere, where its *natural electrical equilibrium* would be the most easily restored.
>
> From this simple Principle, it is evident, that Bodies which are charged with *contrary Electricities,* must tend to *approach* each other, whenever the skirts of their (*oppositely* electrified) *Atmospheres* interfere.
>
> From the same simple Principle, it is also easy to understand, why Bodies, that are charged with the *same kind* of Electricity, tend to *diverge* from each other.

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[5] Principles of Electricity, etc., P. Elmsley, London.

> Every Body that is electrified (whether *in plus* or *in minus*) has a constant tendency to return to its *natural State;* and this causes it to electrify, in a certain degree, *other Bodies* in contact with it, and the Air in its vicinity, in a manner similar to that explained above.

This explanation of electric attraction and repulsion was proposed long before the recognition of energy as a physical quantity; but it may easily be translated into terms of the principle that all elastic reaction to strain is directed to decreasing the potential energy of the strained system. If we substitute for Stanhope's elastic reaction of an electric atmosphere made up of charged air molecules an electric field of strain in an elastic ether, the principle here announced will enable us to explain, not only attraction and repulsion, but all the known phenomena of static electricity.

Twenty years before the publication of Stanhope's *Principles of Electricity* Aepinus had proved to his own satisfaction that charged bodies are not surrounded by an electric atmosphere of any kind. In 1759 Aepinus published his celebrated work, *Tentamen Theoriae Electricitatis et Magnetismi,* in which he stated his adherence to the general principles of Franklin's theory of a single electrical substance and attempted to develop a similar one-fluid theory of Magnetism. Aepinus expressed a firm belief that the electric fluid was wholly distinct from the ether of space, and maintained that it was confined to the limits of the electrified body and did not form an electrical atmosphere or effluvium extending into surrounding space. It is probable that it is for this reason that Aepinus is sometimes credited with being the principal founder of the theory of electrical forces acting at a distance. Thus, Whittaker, in *A History of the Theories of Aether and Electricity,* p. 48, says:

> The theory of effluvia was finally overthrown, and replaced by that of action at a distance, by the labours of one of Franklin's continental followers, Francis Ulrich Theodore Aepinus.

The latter part of this statement seems hardly justifiable in view of Aepinus' own statement of his belief. Thus on page 7 of *Tentamen Theoriae* Aepinus says:[6]

> I do not approve of the doctrine which assumes the possibility of action at a distance, for I hold as an indisputable axiom the statement that a body cannot act at a place where it is not; and if it should ever be proved that a certain attraction or repulsion does not altogether depend upon an external pressure or an internal impulse, then I think we have been reduced to such a position that we are compelled to conclude that motions of this kind are not produced by a physical force, but by spirits or other beings, as to which I cannot be induced to believe that this idea has any foundation in the world.

The arguments which led Aepinus to deny the existence of an electrical atmosphere seem to have been somewhat as follows: Since from Franklin's electrical theory all bodies upon the earth must be electrified,+electrification meaning that a body is more highly electrified than the earth and—electrification meaning that a body is electrified to a lower intensity than the earth, if charged bodies have an electrical atmosphere, then all bodies on the earth's surface should have an electrical atmosphere and by decreasing the capacity of an insulated body in the same electrical state as the earth it should be possible to increase the intensity of its atmosphere until it would become appreciable. Cavendish gives a similar reason for the same belief a few years later.

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[6] Translation by Professor Jefferson Elmore.

In 1771 Cavendish presented a paper to the Royal Society entitled *An Attempt to Explain Some of the Principal Phenomena of Electricity by means of an Elastic Fluid.* In the first paragraph of this paper Cavendish says:

> Since I first wrote the following paper, I find that this way of accounting for the phaeomena of Electricity is not new. Aepinus, in his *Tentamen Theoriae Electricitatis et Magnetismi,* has made use of nearly the same hypothesis that I have; and the conclusions he draws from it agree nearly with mine, as far as he goes.

On page 94 of his *Electrical Researches,* as edited by Maxwell, Cavendish gives his arguments against the existence of an electrical atmosphere as follows:

> That the attraction and repulsion of electricity extend to considerable distances is evident, as corks are made to repel by an excited tube held out at a great distance from them. That the electric atmospheres themselves cannot extend to any perceptible distance, I think, appears from hence, that if two electric conductors be placed ever so near together so as not to touch, the electric fluid will not pass rapidly from one to the other except by jumping in the form of sparks, whereas if their electric atmospheres extended to such a distance as to be mixed with one another, it should seem as if the electricity might flow quietly from one to the other in like manner as it does through the pores of any conducting matter.
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> But the following seems a stronger reason for supposing that these atmospheres cannot extend to any perceptible distance from the body they surround, for if they did it should seem that two flat bodies whenever they were laid upon one another should always become electric thereby, for in that case there is no room for the electric atmosphere to extend to any sensible distance from those surfaces of the bodies which touch one another, so that the electric fluid which before surrounded those surfaces would be forced round to the opposite sides, which would therefore become overcharged with electricity, and consequently appear electrical, which is contrary to experience.

These papers of Aepinus and Cavendish seem to the present writer to furnish the starting point for that ether theory of electric attraction and repulsion which reached its extreme development in the writings of Faraday and his successors, but which seems for a time immediately following the work of Cavendish and Coulomb to have given place to the theory of action at a distance. At any rate, they mark the beginning of a rapid decline of the notion of electric atmospheres, though Stanhope's theory of the electrification of the surrounding air was published eight years after the presentation of Cavendish's paper to the Royal Society.